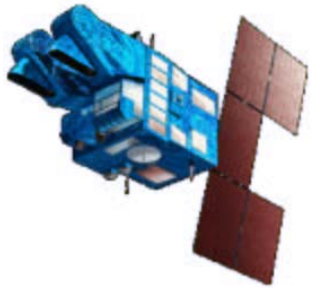
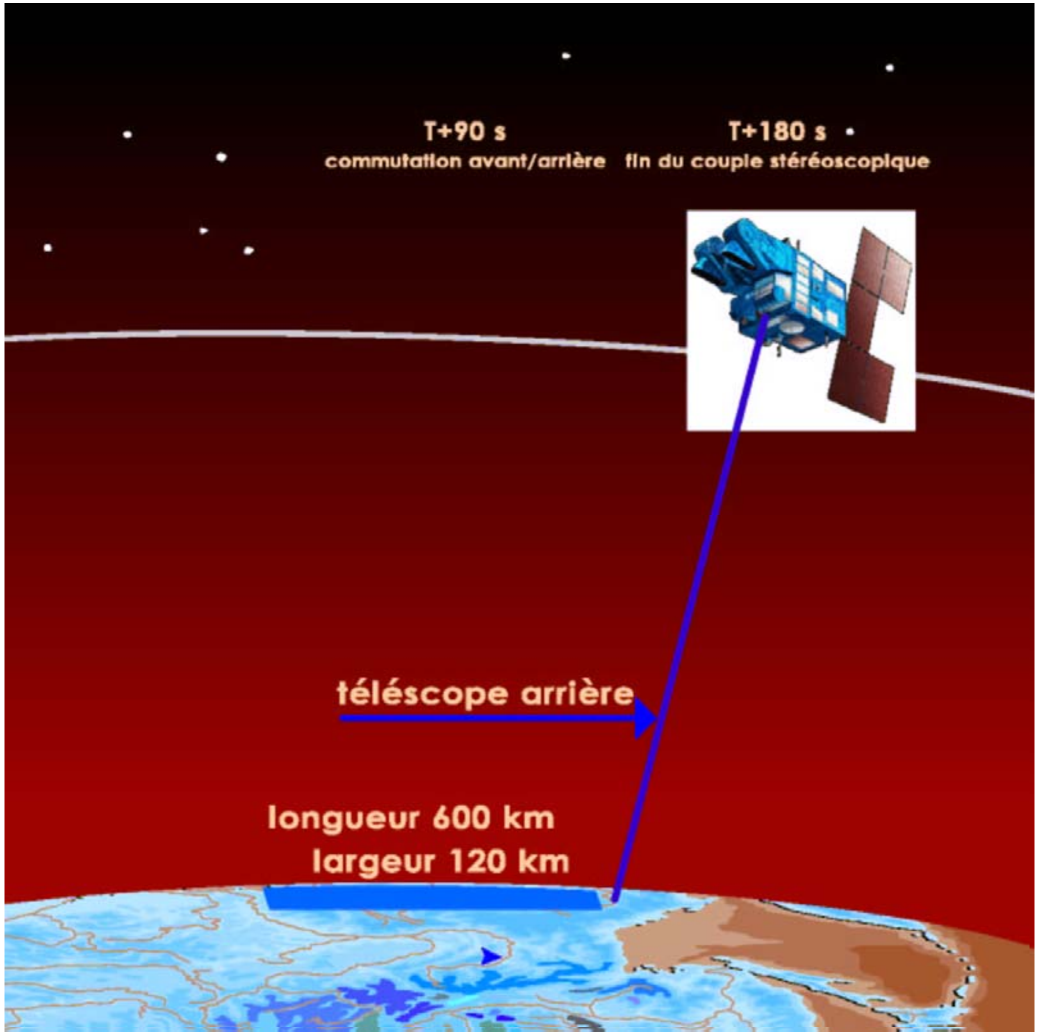
Monitoring the Earth Surface from space

- Picture of the surface from optical Imagery, i.e. obtained by telescopes or cameras operating in visual bandwith.
- Shape of the surface from radar imagery
- Surface deformation from satellite geodesy : SLR, VLBI, DORIS, GPS

Optical Imagery : basic principles

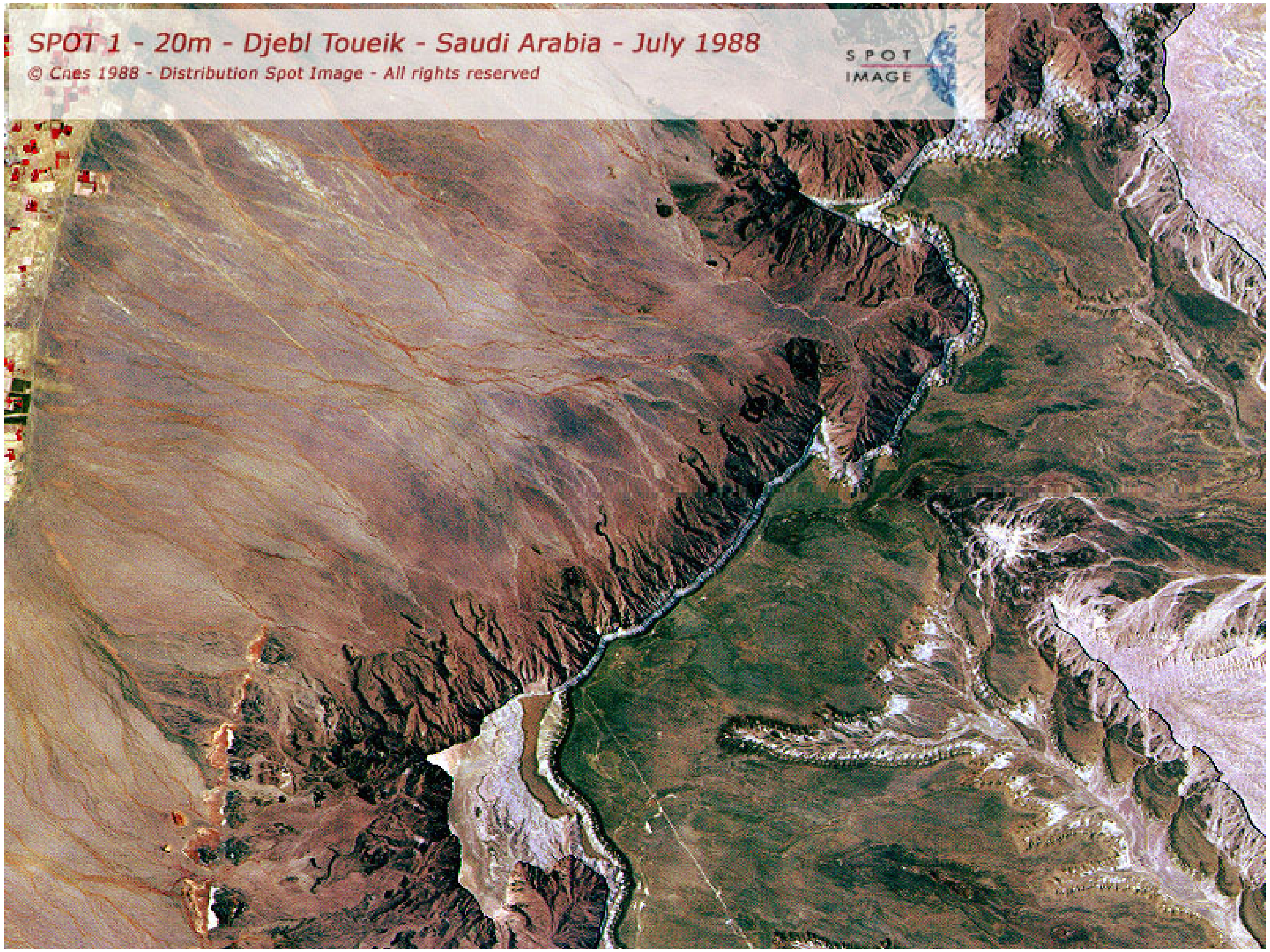




SPOT – Ikonos – etc..

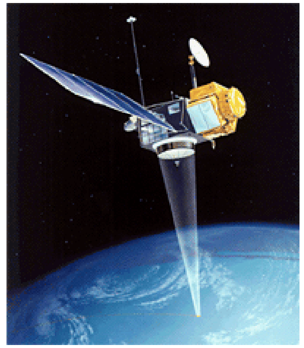
SPOT example :
The satellite has 2 telescopes :
The first one acquires ahead, the second one behind. Therefore we have **2 tracks** with a slightly different view of the same band of ground.
This allow **stereoscopic** view, i.e. 3-D vision

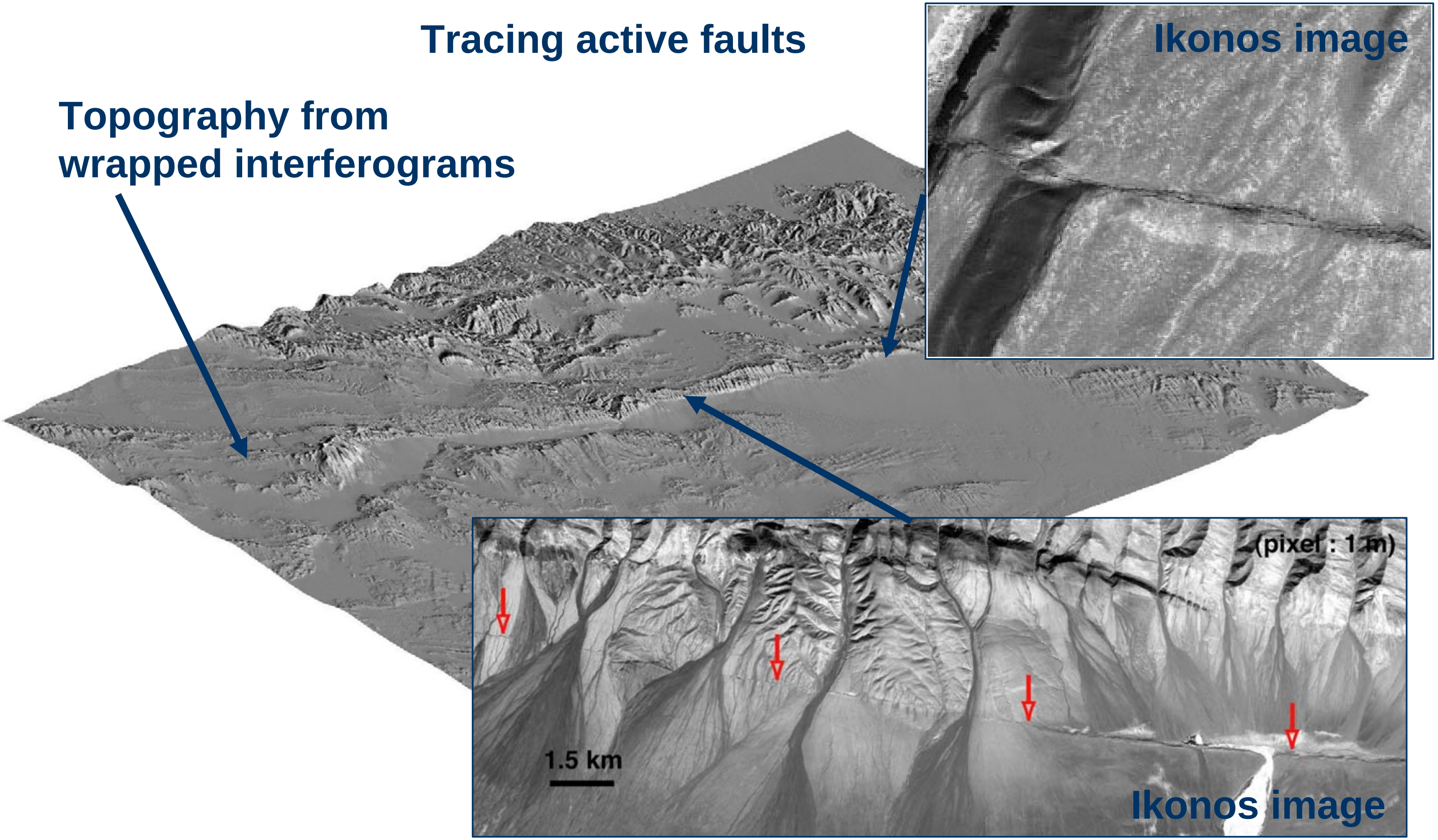
Optical imagery : Spot 1 (20m)



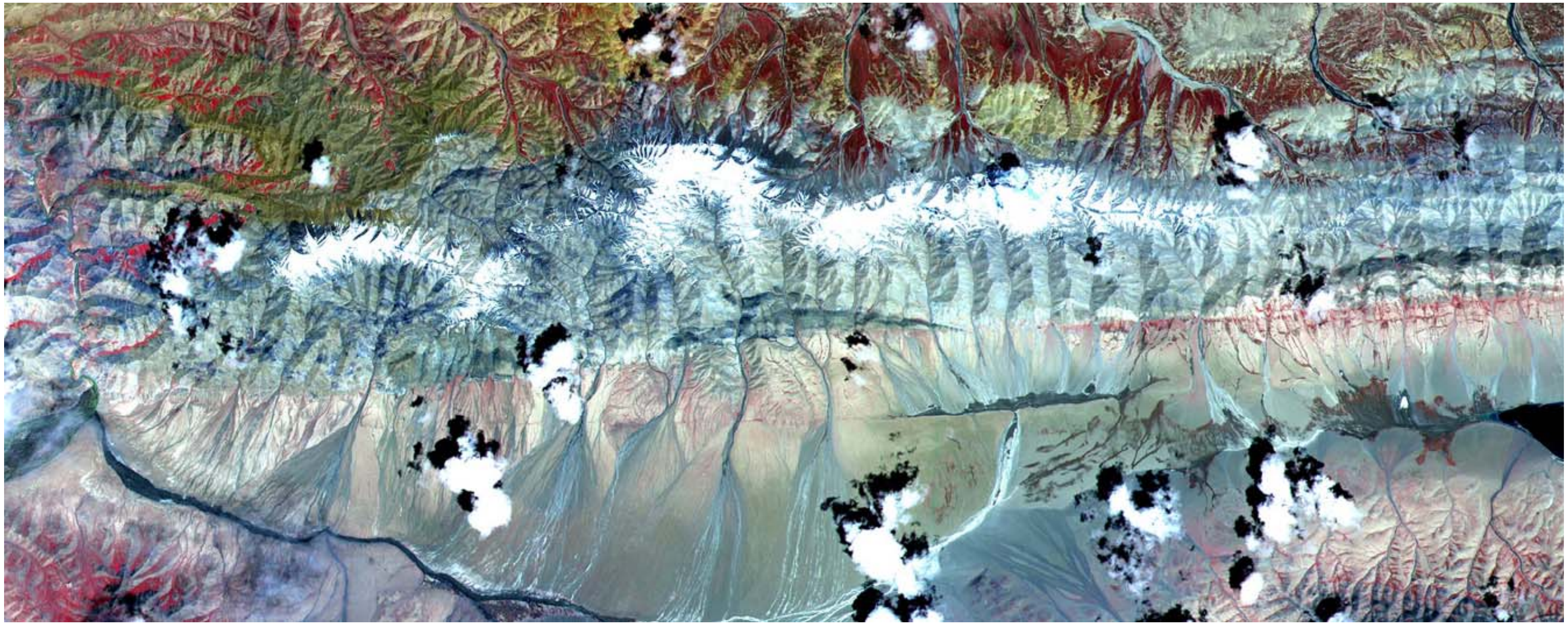
Optical imagery : Spot 5 (5m)

Optical imagery : Ikonos (1m)

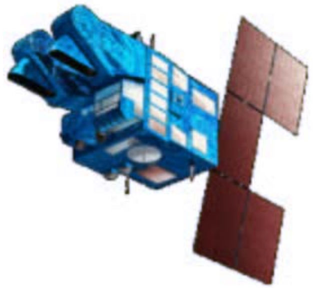




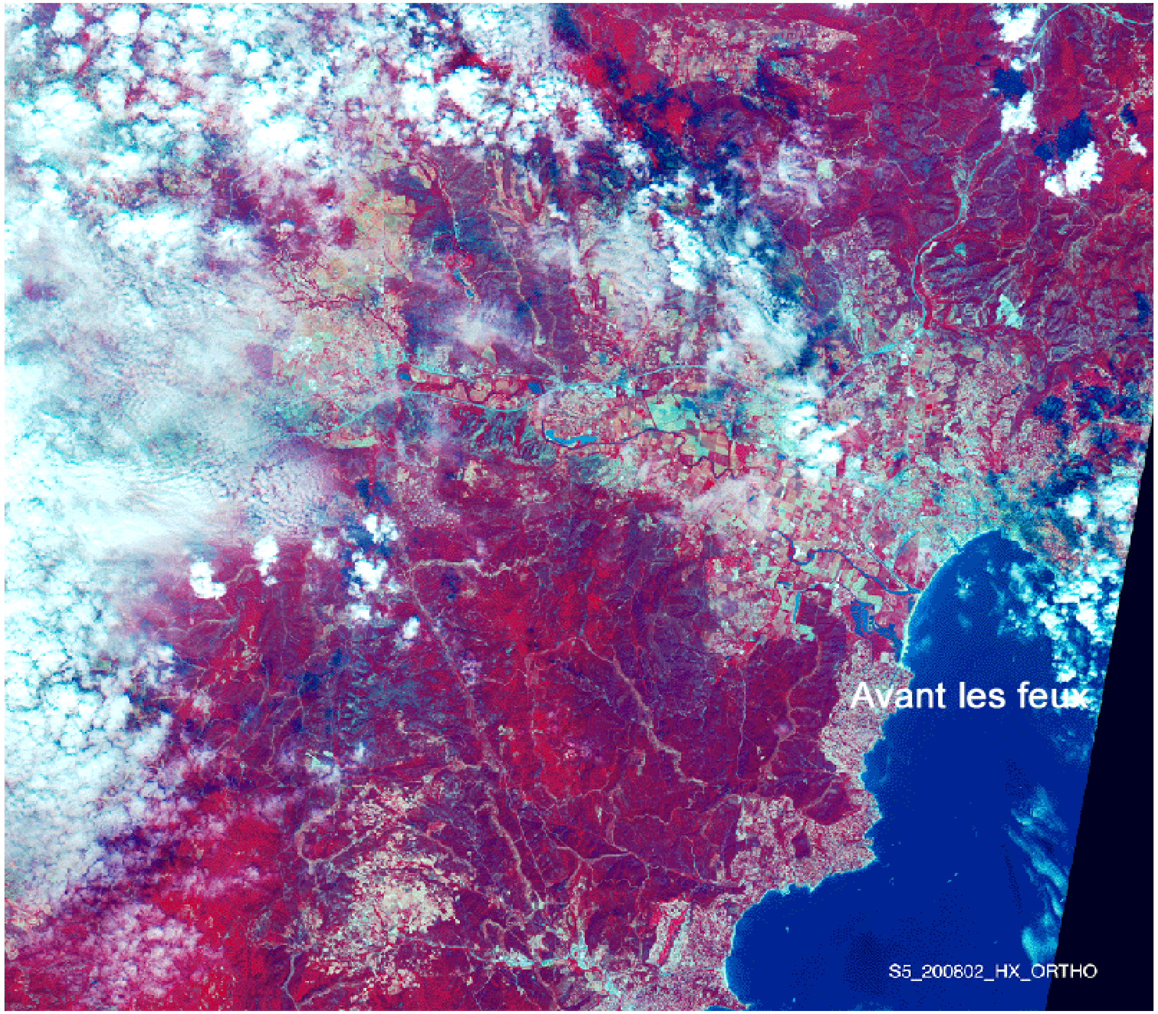
Optical imagery : ASTER (infrared)



The **Kunlun** Fault in Tibet. Left-lateral motion along the 1500 km length of the Kunlun has occurred uniformly for the last 40,000 years at a rate of 1.1 cm/yr, giving a cumulative **offset of more than 400 m**. In the image, two splays of the fault are clearly seen crossing the image from east to west. The northern fault juxtaposes sedimentary rocks of the mountains against alluvial fans; its trace is also marked by lines of vegetation, appearing red in the image. The southern, younger fault cuts through the alluvium. A dark linear area in the center of the image is wet ground where groundwater has pounded against the fault. Measurements from the image of displacements of young streams that cross the fault show 15 to 75 m of left-lateral offset.

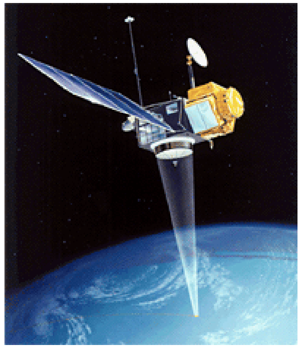


Monitoring changes : Spot 5

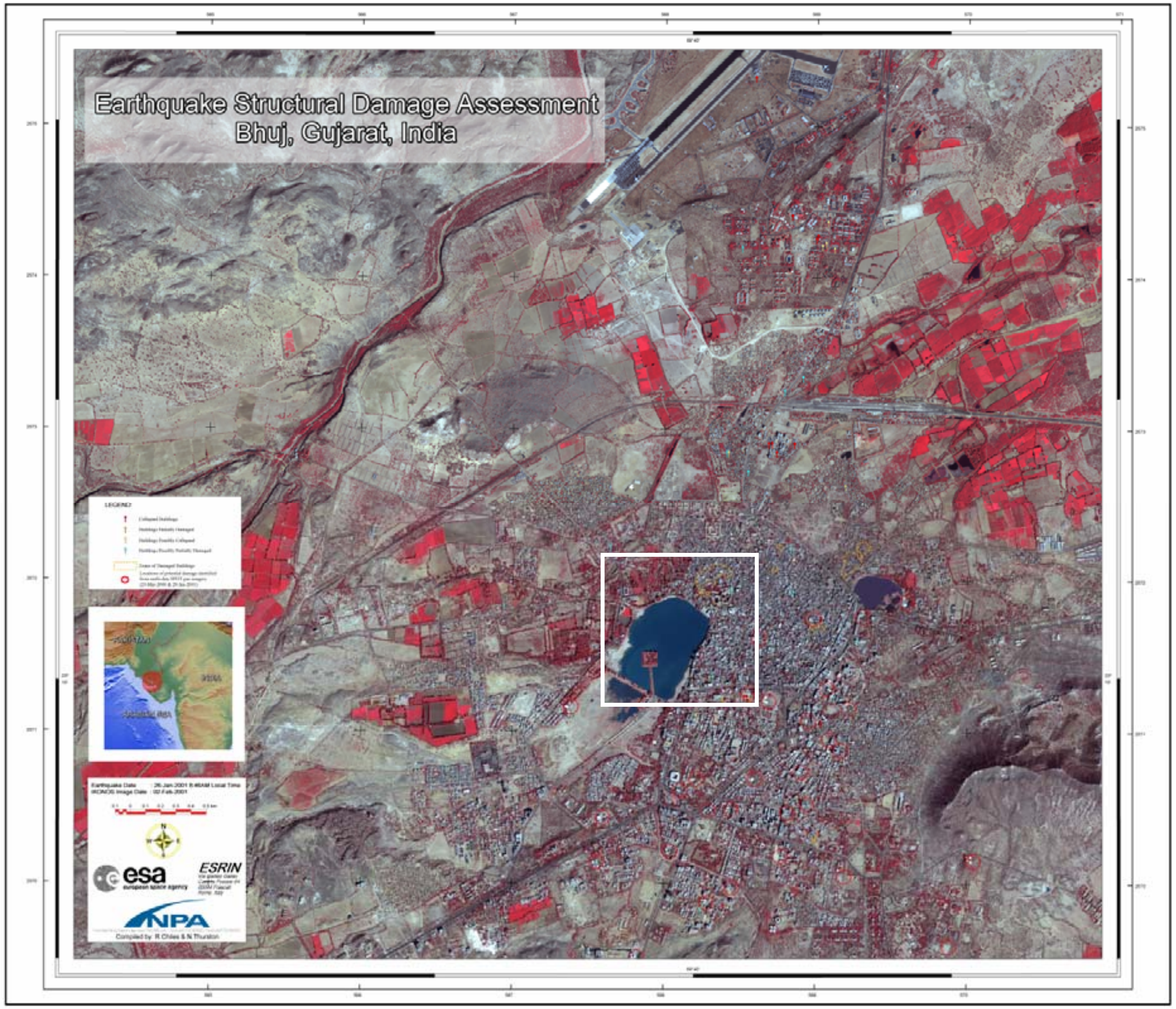


Forest fires appear like dark blue areas

Spot passes every day, so evolution can be monitored daily

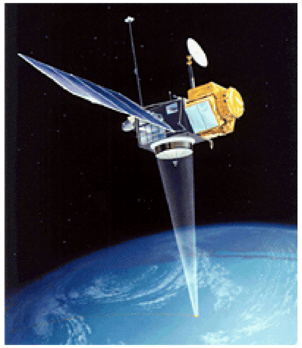


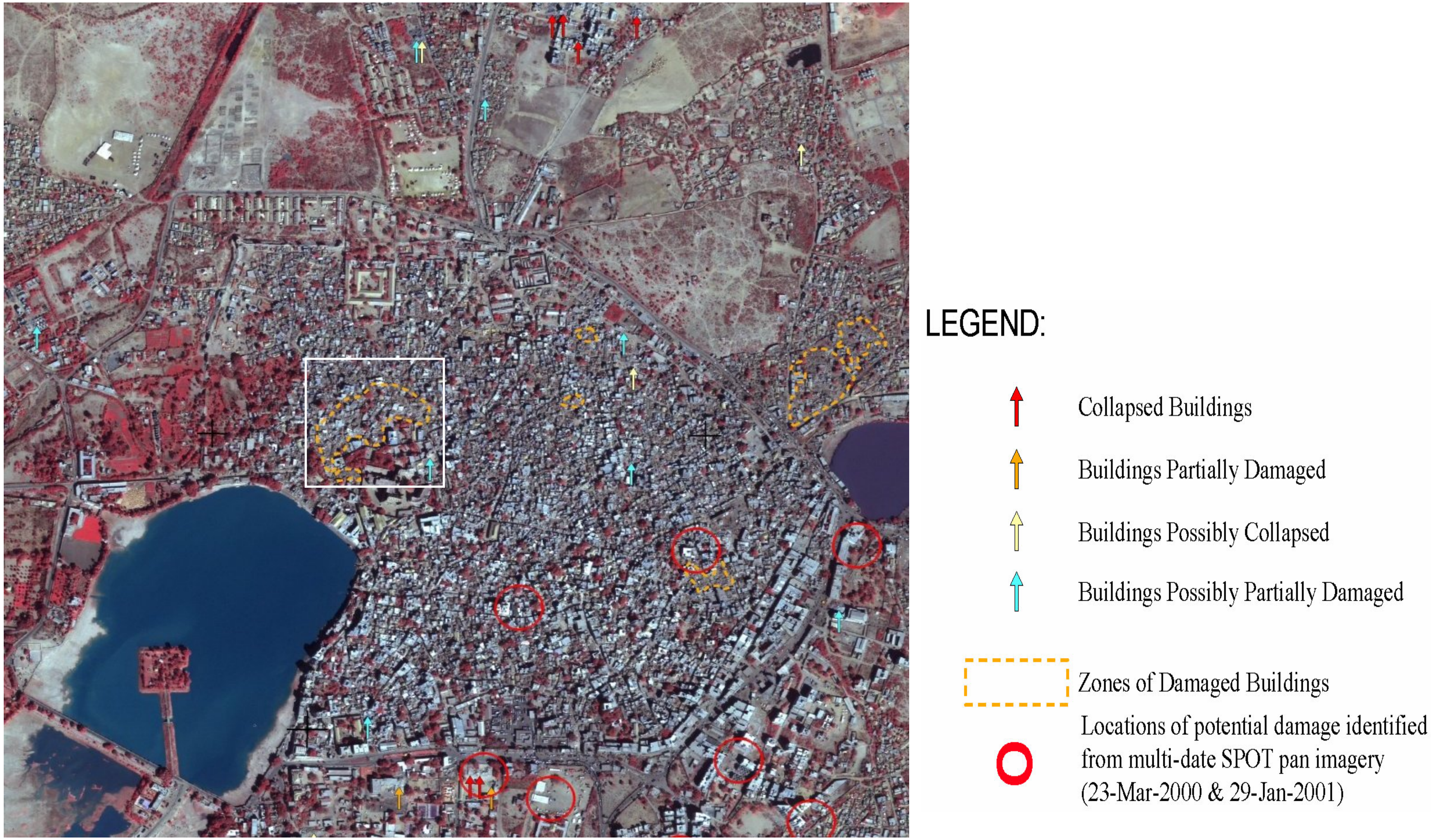
Damage assesment : Ikonos 2

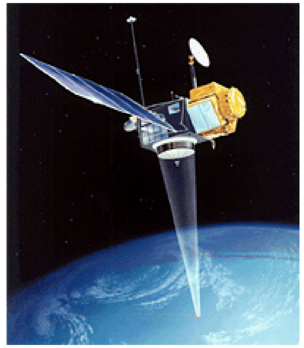


Panchromatic image acquired 7 days after the Earthquake

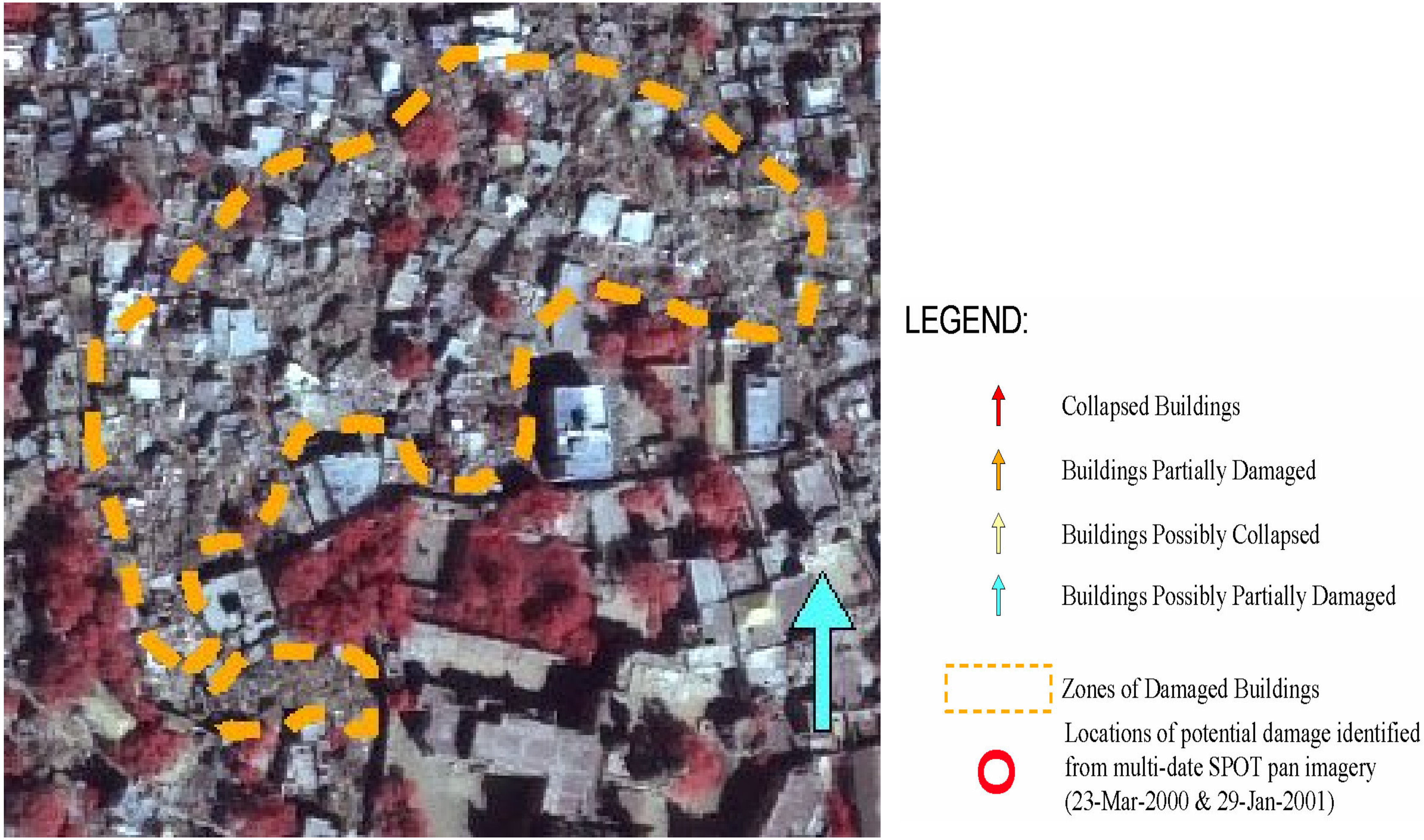
Damage assessment : Ikonos 2



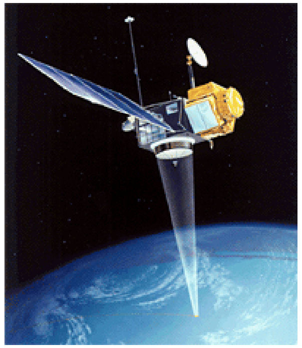




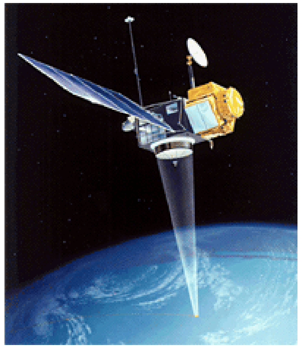
Damage assessment : Ikonos 2

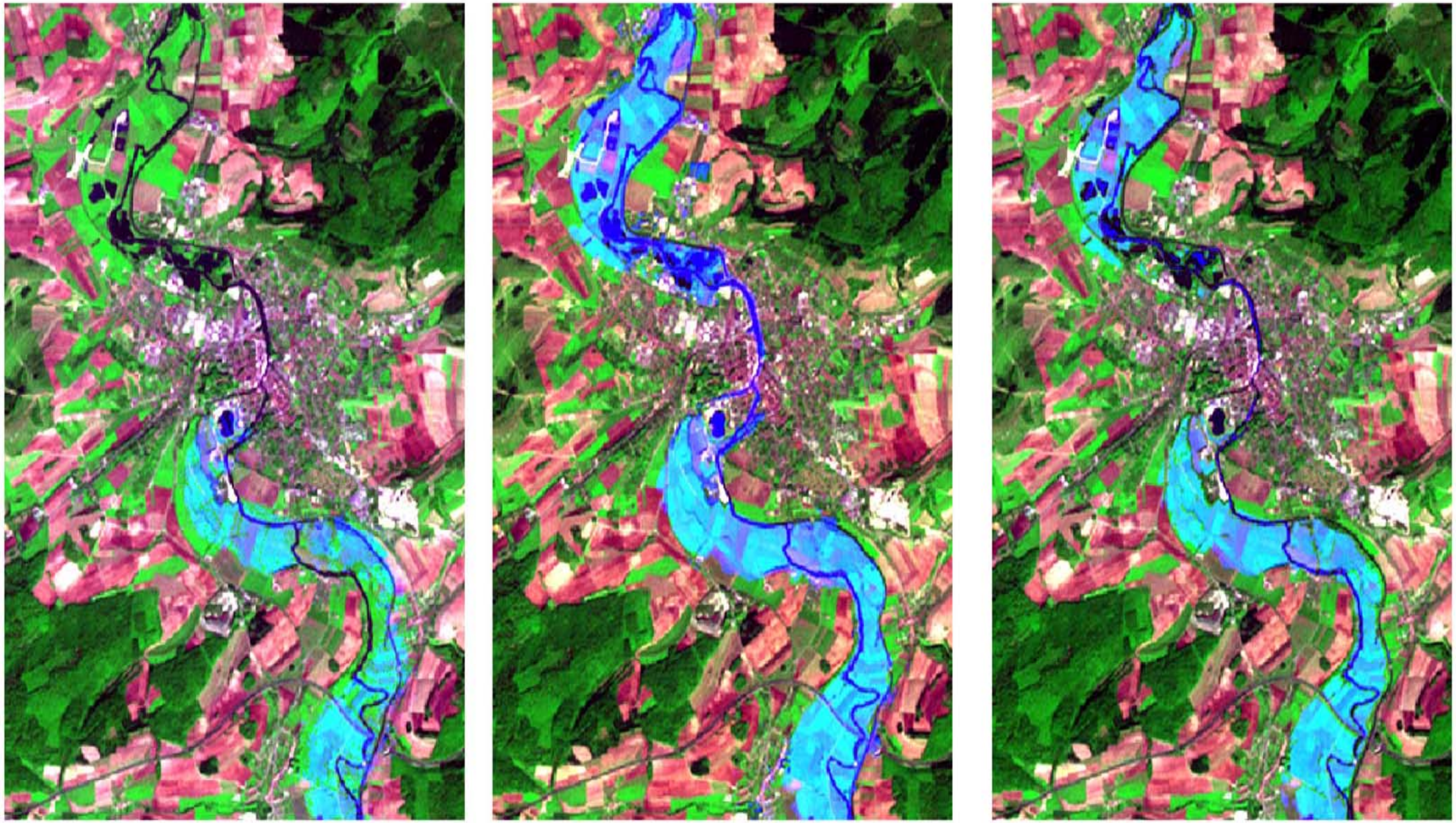


Damage assessment : Ikonos 2

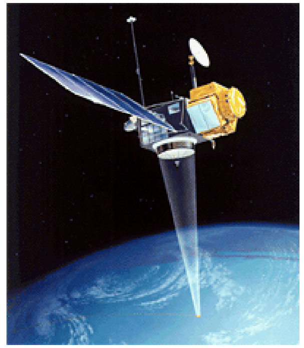


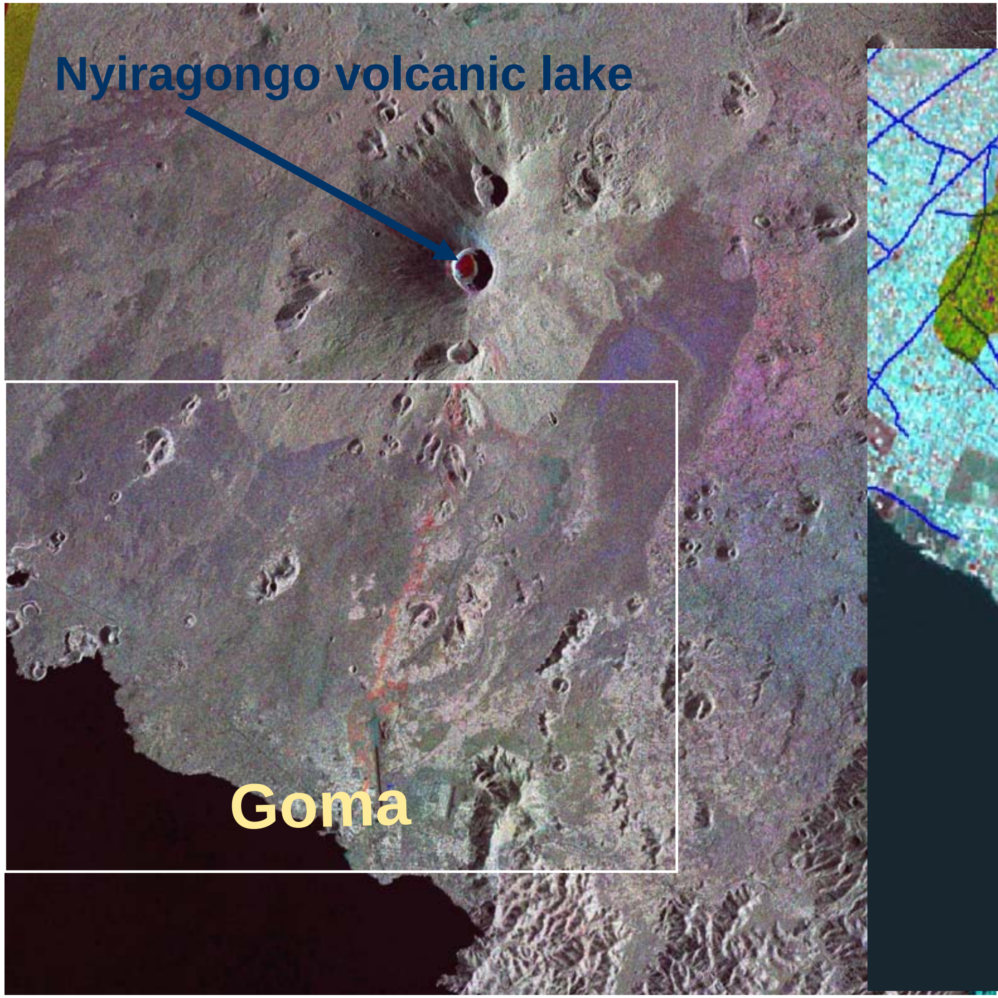
River Flooding : SPOT5

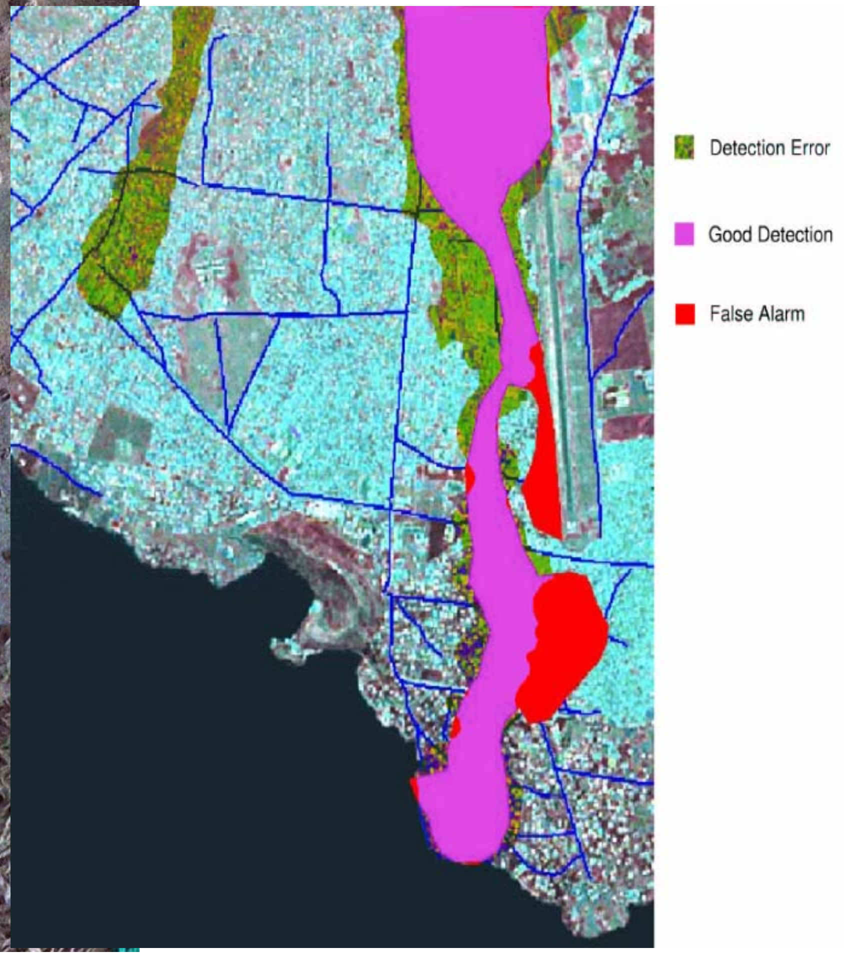




Nyirakongo volcanic eruption



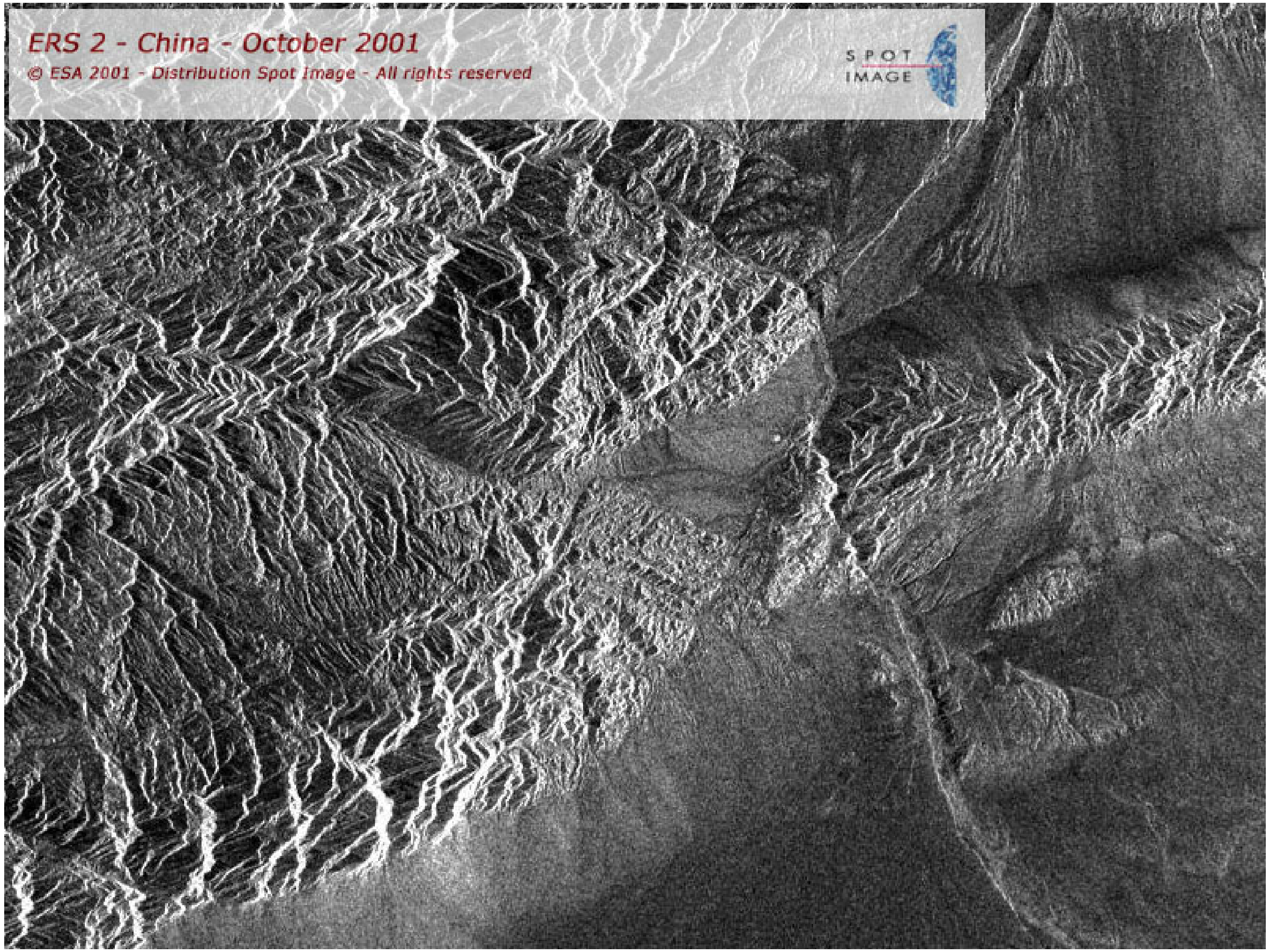




Radar detection

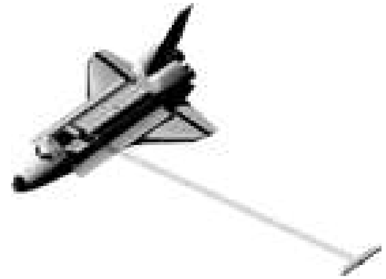
This image is a part of Orissa acquired by the Radarsat Satellite . The picture clearly shows flood inundated areas. **RADARSAT**'s Synthetic Aperture Radar (SAR) has the capability to penetrate darkness, clouds ,rains and haze. It provides solution for acquiring data over dynamic areas like tropical, coastal and polar region. This image was captured on 2.11.1999 in Scan SAR wide mode (500Kmx500Km area in **100m resolution**).

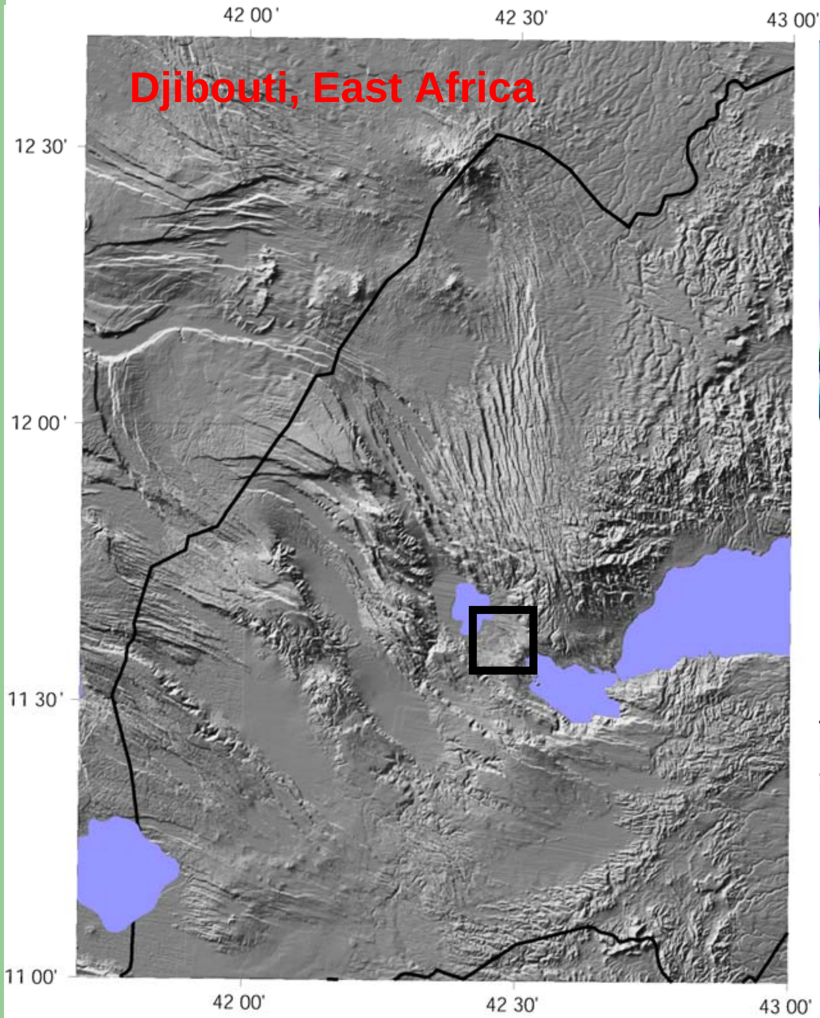
Radar Digital Elevation Model

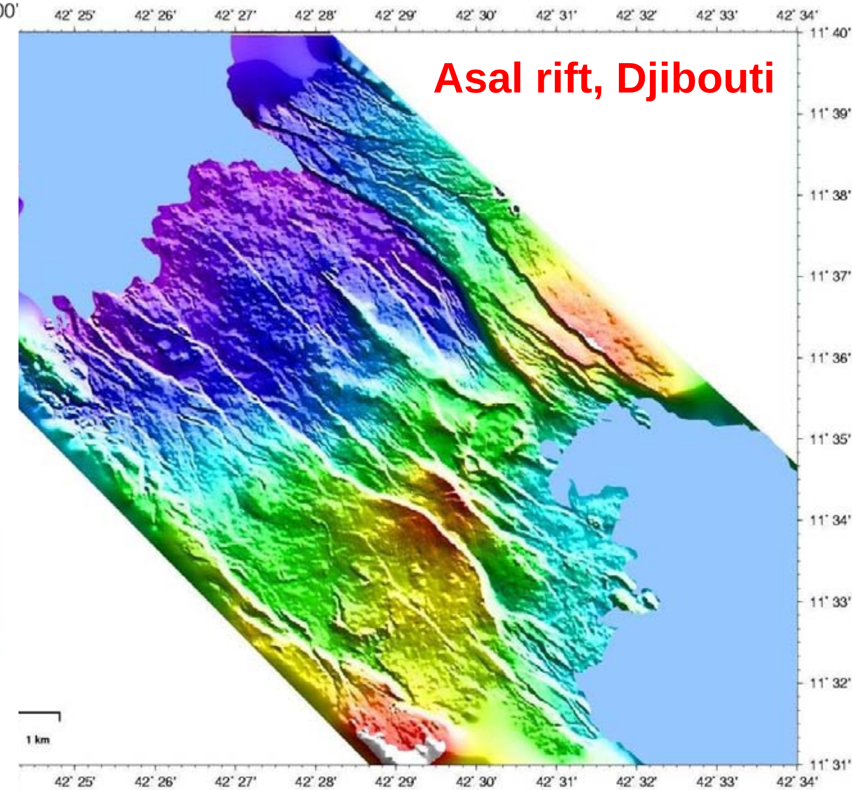


Because the radar signal goes through clouds, the main advantage of the system is that it is all weather!

Radar Digital Elevation Model





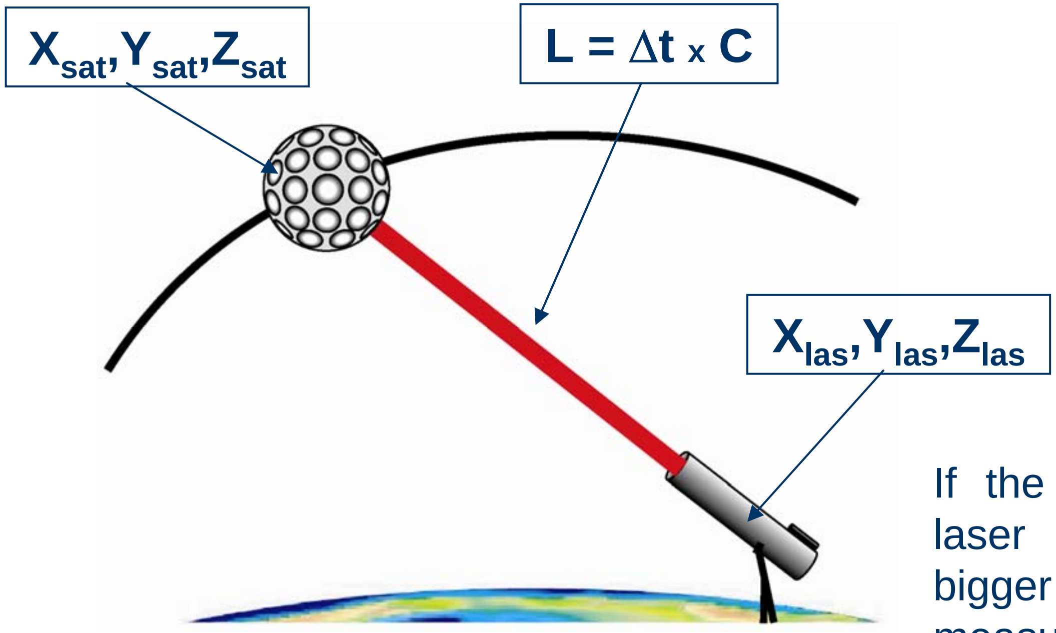


The **S**huttle **R**adar **T**opographic **M**ission (SRTM) covered the whole Earth in 10 days and delivered a 30 m resolution global **D**igital **E**levation **M**odel (DEM)

Earth surface deformation

Satellite Laser Ranging

High energy laser firing at satellites enable to determine the position of the satellite and then the Geoid, assuming the station position is know. On reverse, assuming one knows the satellite position (i.e. the earth gravity field), then by measuring the satellite-station distance one can determine the station position. The time is measured with a precision of about **0.1ns to 0.3 ns** (3.10^{-10} sec), which give a precision of about **3 to 10 cm** on the measured length, hence on the station position.



$$X_{las} = X_{sat} - L_x$$
$$Y_{las} = Y_{sat} - L_y$$
$$Z_{las} = Z_{sat} - L_z$$

$$pos_{las} = pos_{sat}(t_i) - L(t_i)$$

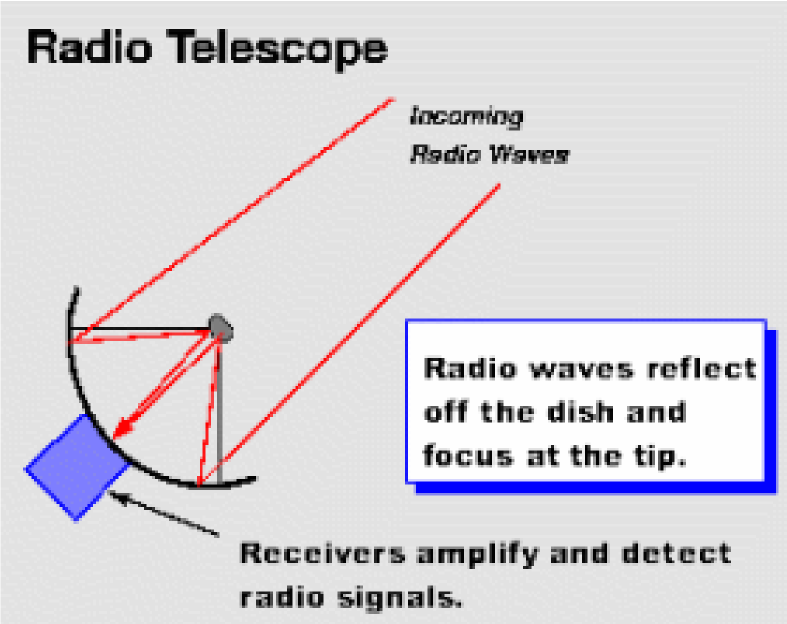
With : ti = time of i^{th} measurement along the orbit

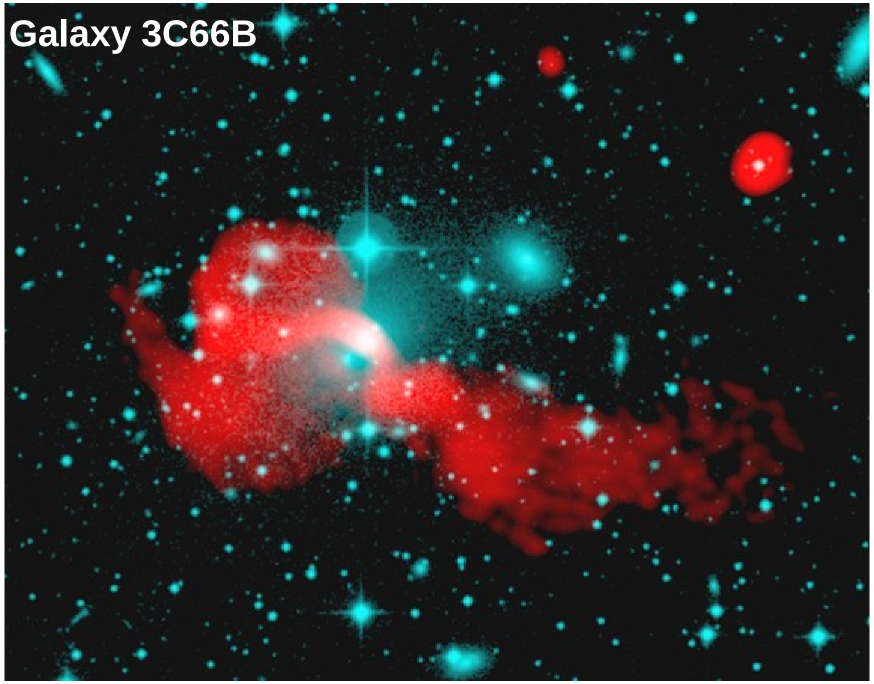
If the earth surface deforms, then the laser station moves. If this motion is bigger than a few cm, then the measurement detects it !

Earth surface deformation

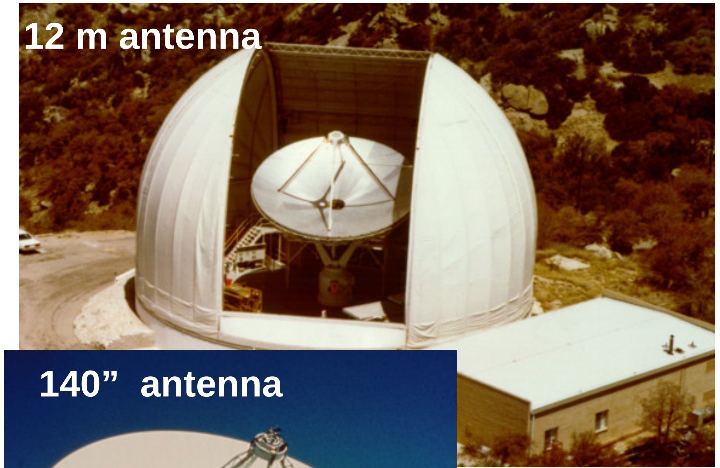
Radio Telescope principle

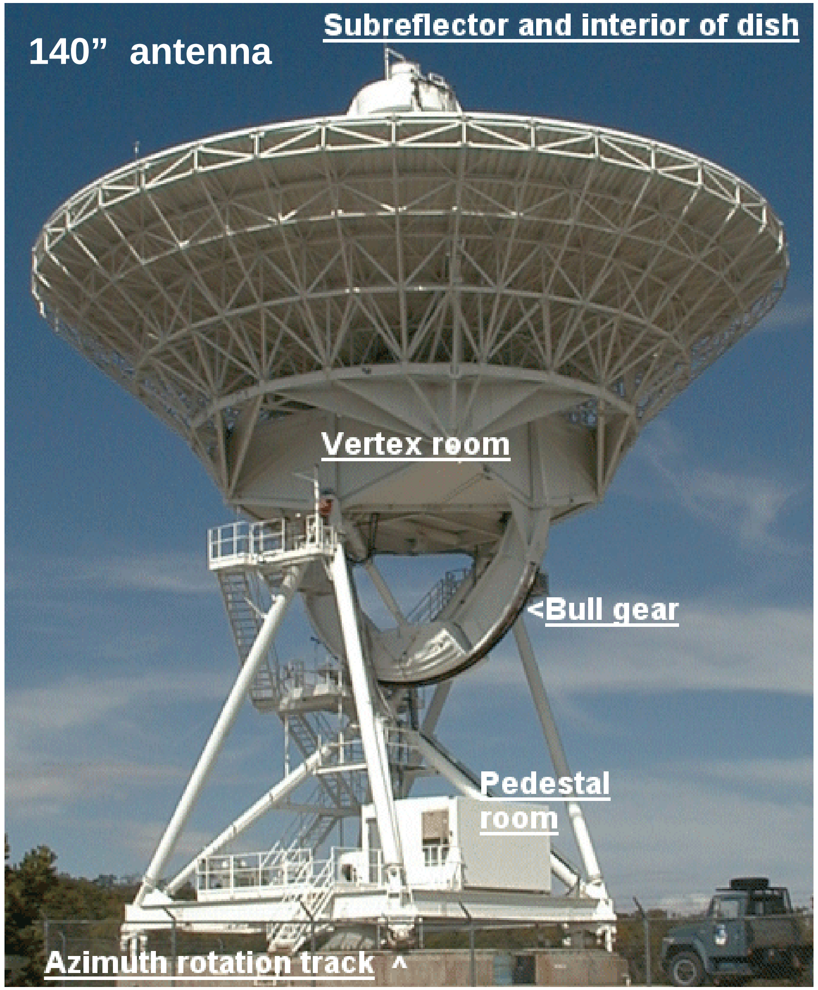
Radio telescopes are used to study naturally occurring radio emission from stars, galaxies, quasars, and other astronomical objects between wavelengths of about 10 meters (30 megahertz [MHz]) and 1 millimeter (300 gigahertz [GHz]). At wavelengths longer than about 20 centimeters (1.5 GHz), irregularities in the ionosphere distort the incoming signals. Below wavelengths of a few centimeters, absorption in the atmosphere becomes increasingly critical. the effective angular resolution and image quality **is limited only by the size of the instrument.**





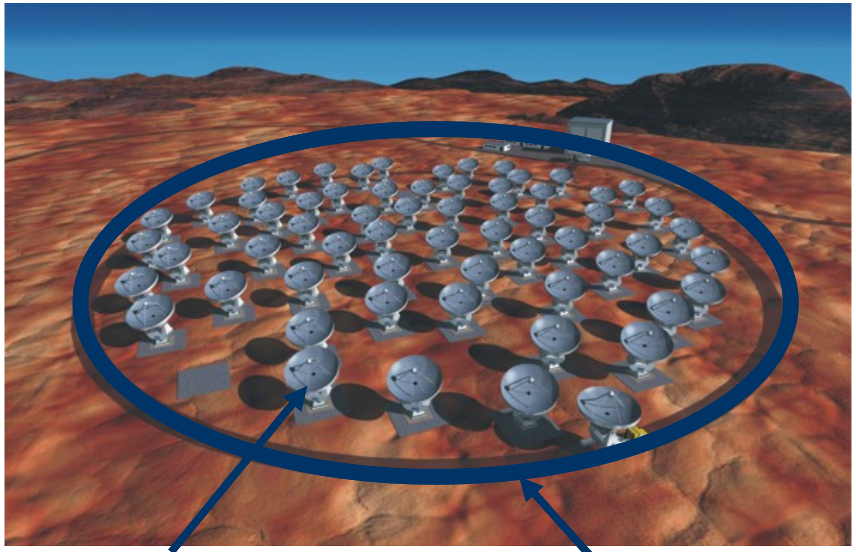
Bigger antennas





Very Large Base Interferometry (VLBI)

It is extremely difficult to built antennas bigger than 20-30 meters diameter…
But, one **single large** mirror (or antenna) can be replace by **many small** mirrors (or antenna). The size of the image wills be equivalent. Thus, an array of small antennas make a **virtual** big antenna of equivalent size the size of the array.

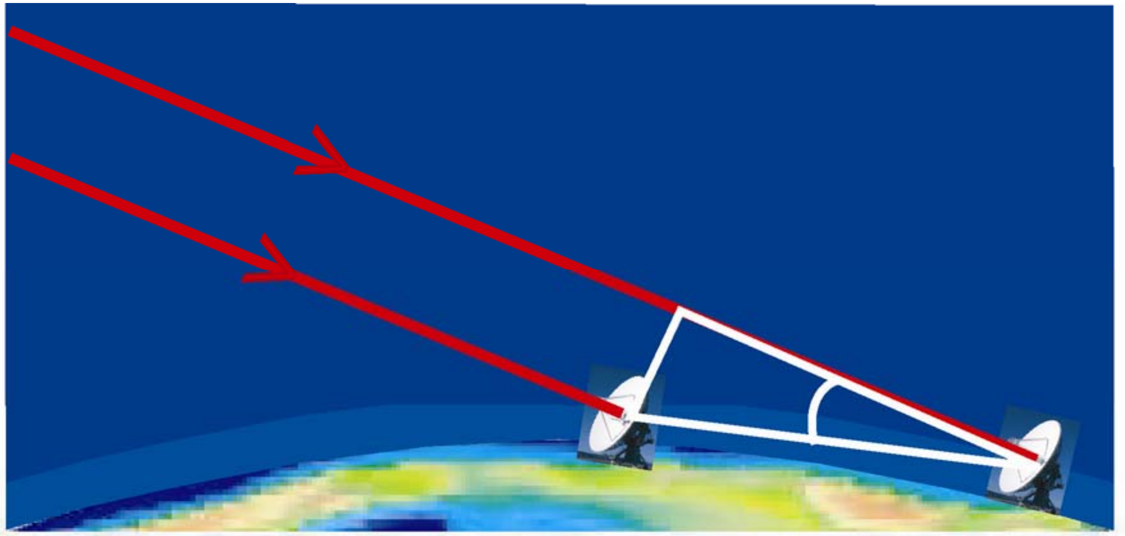


Single small antenna

virtual antenna

Very Large Base Interferometry (VLBI)

One can reconstruct a precise image of the observed object, knowing precisely the distances between the individual antennas. If these distances are not well known, then the image is fuzzy.
Again, reversing the problem, focusing a known image allow to determine the distances between stations.



The radio wavelength arrives at first antenna at time **t**, and at the second antenna at time **t + Δt**.

The additional distance is : **Δt .C**

Which we can easily convert into distance between stations (knowing the angle=difference in latitude)

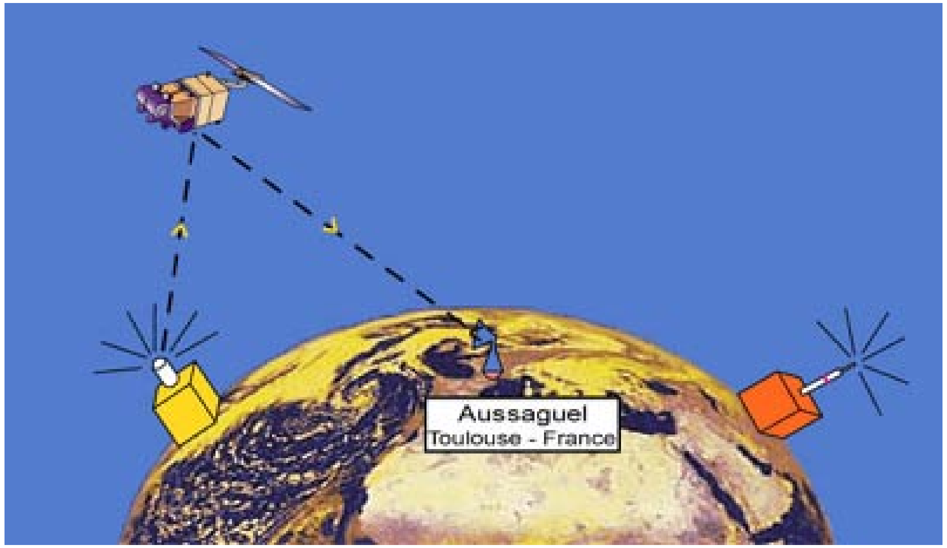
The obtained precision is around **1 millimeter** !

DORIS (Doppler system)

A wavelength is broadcasted by a ground station with a given frequency. A satellite is receiving this signal. Because the satellite is moving, the frequency it receives is shifted. This is the Doppler effect.

For a velocity **v**, the frequency ν will be shifted by a quantity equal to νx **v/c**

The complete formula for **V** not // to line of view is : $\nu' = \nu \frac{1 - \cos\phi \frac{v}{c}}{\sqrt{1 - \frac{v^2}{c^2}}}$



For a satellite velocity and position are linked by the Keplerian equation of its orbit.

Thus, measuring the Doppler shift allows to determine the Station to Satellite distance

DORIS (Doppler system)

The obtained precision on station position is around 1-3 cm

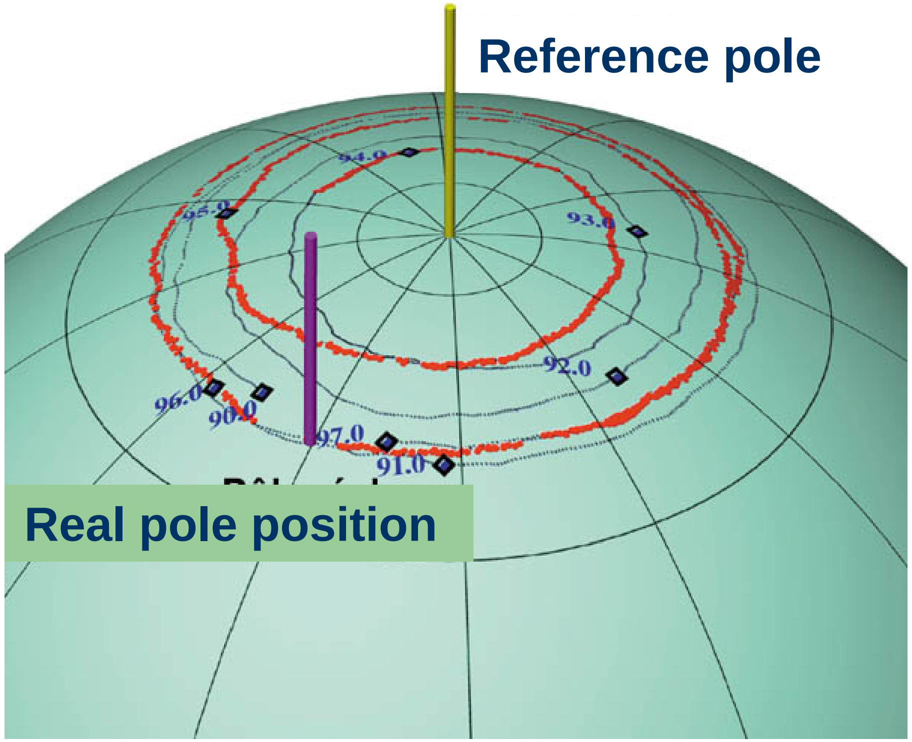
DORIS beacons

DORIS GLOBAL network
~60 stations covering the whole Globe

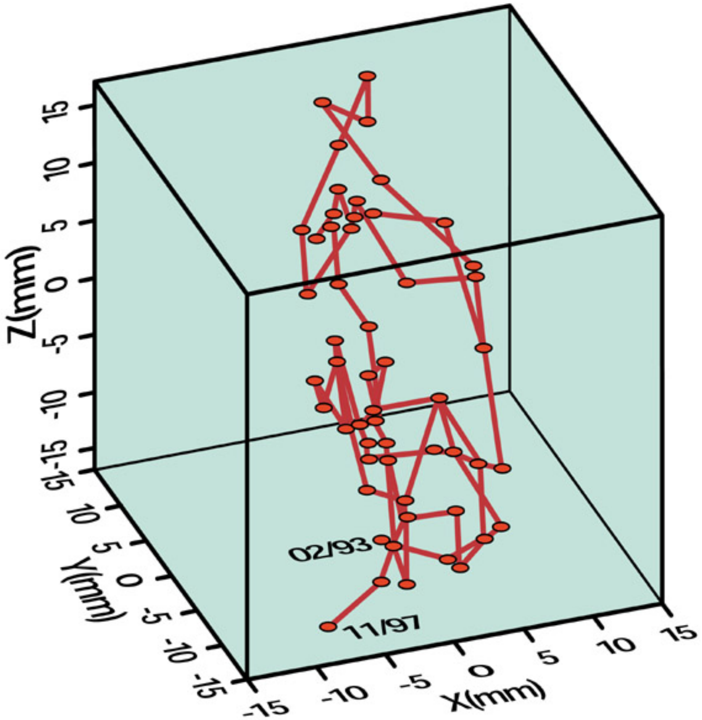
DORIS (Doppler system)

DORIS allow to detect motion of stations but also the motion of the whole network (as a polyhedron) in space. Thus we can determine the **oscillations of planet Earth.** These oscillations have a complex frequency contains from Milankovitch period (26 000 years) to Chandler Wobble (400 days) and daily adjustments due to atmospheric loads

Motion of the Earth axis of rotation

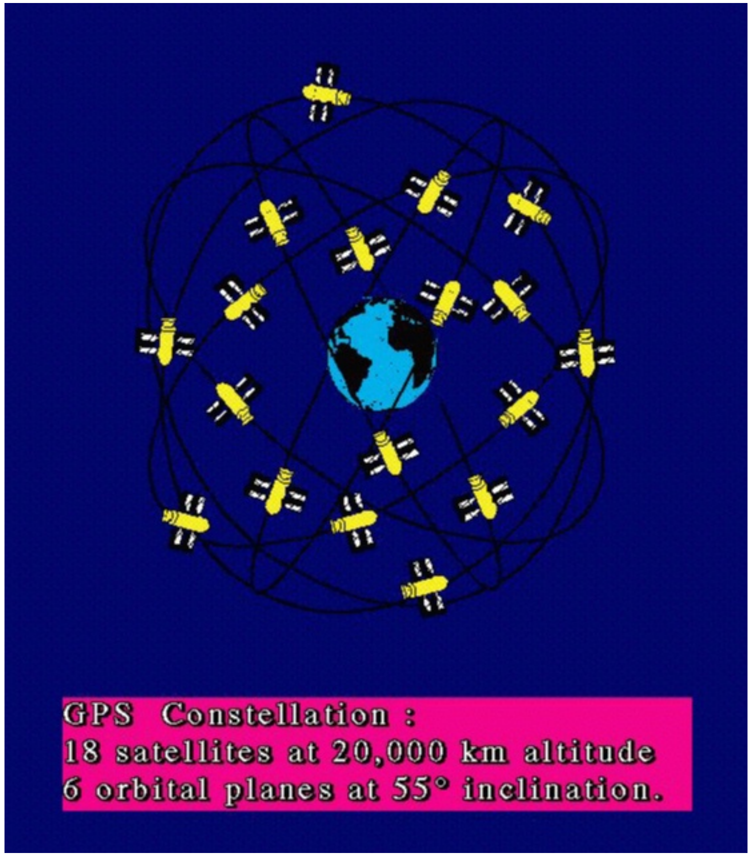


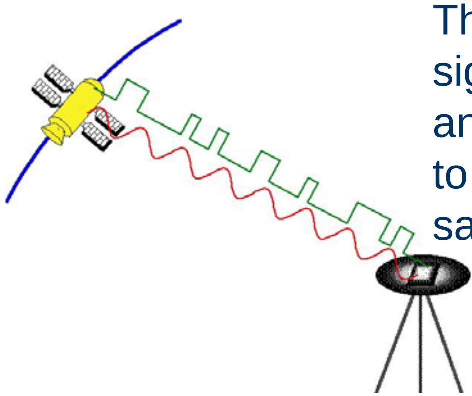
Motion of the Earth gravity center



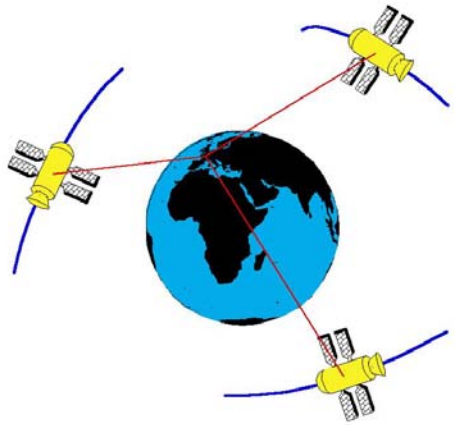
GPS (Global Positioning System)

GPS was created in the 80s' by the US Department of Defense for military purposes. The objective was to be able to get a precise position anywhere, anytime on Earth.





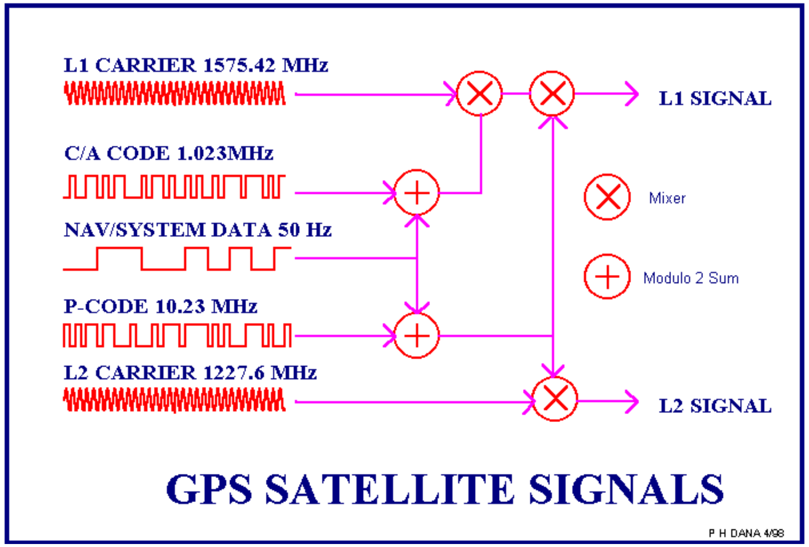
The satellites send a signal, received by a GPS antenna. Again, this allow to measure the distance satellite to antenna



With at least 3 satellites visible at the same time, we can compute instantaneously the station position. The precision can be as good as 1 millimeter

GPS (Global Positioning System)

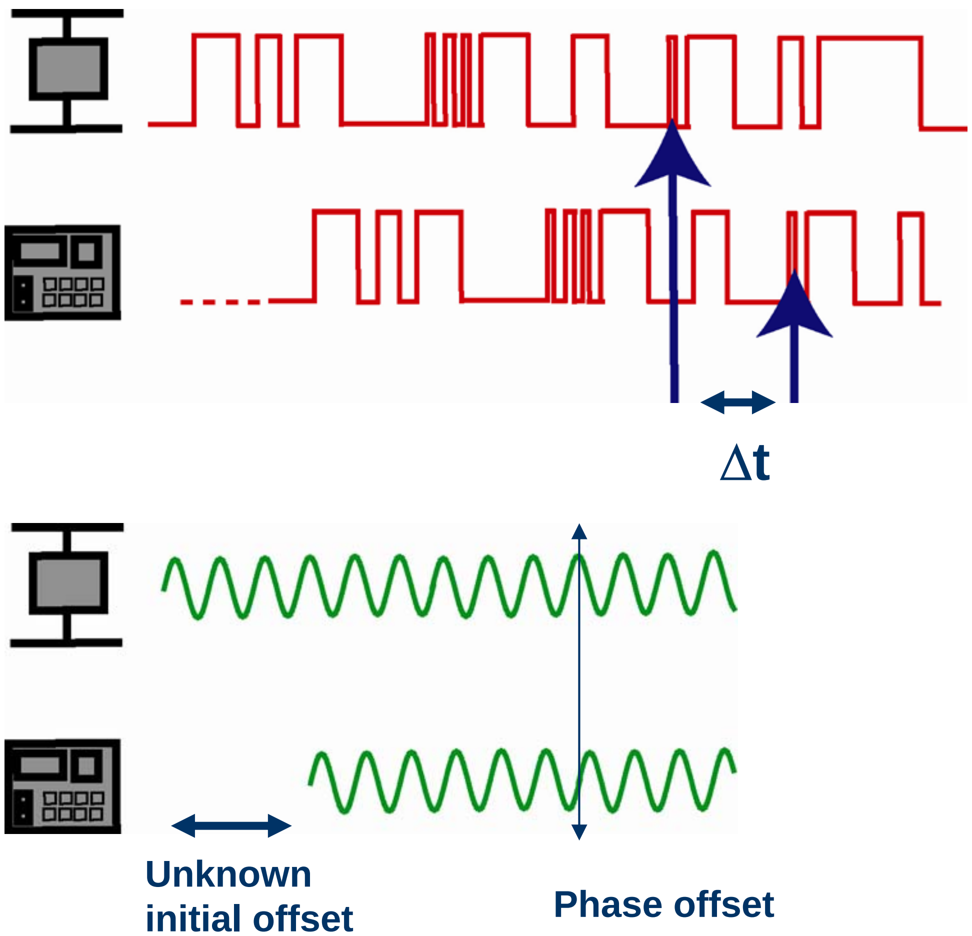
satellites transmit two microwave carrier signals. The **L1 frequency** (**1575.42 MHz**) carries the navigation message and the low precision code signals. The **L2 frequency** (**1227.60 MHz**) is used to measure the ionospheric delay for precise positioning applications.



Three binary codes shift the L1 and/or L2 carrier phase :

1. The **C/A Code** (Coarse Acquisition) modulates the **L1** carrier phase. The C/A code is a repeating 1 MHz Pseudo Random Noise (PRN) Code. This noise-like code modulates the L1 carrier signal, "spreading" the spectrum over a 1 MHz bandwidth. The C/A code repeats every 1023 bits (one millisecond).
2. The **P-Code** (Precise) modulates both the **L1** and **L2** carrier phases. The P-Code is a very long (seven days) 10 MHz PRN code. In the Anti-Spoofing (AS) mode of operation, the P-Code is encrypted into the Y-Code. The encrypted Y-Code requires a classified AS Module for each receiver channel and is for use only by authorized users with cryptographic keys.
3. The **Navigation Message** also modulates the L1-C/A code signal. The Navigation Message is a 50 Hz signal consisting of data bits that describe the GPS satellite orbits, clock corrections, and other system parameters

GPS (Global Positioning System)



pseudo-distance Measurement:

Accurate to 30 m if C/A code (pseudo frequency of 1 MHz)

Accurate to 10 m if P code (pseudo frequency of 10 MHz)

Easy because code never repeats itself over a long time, i.e. no ambiguity

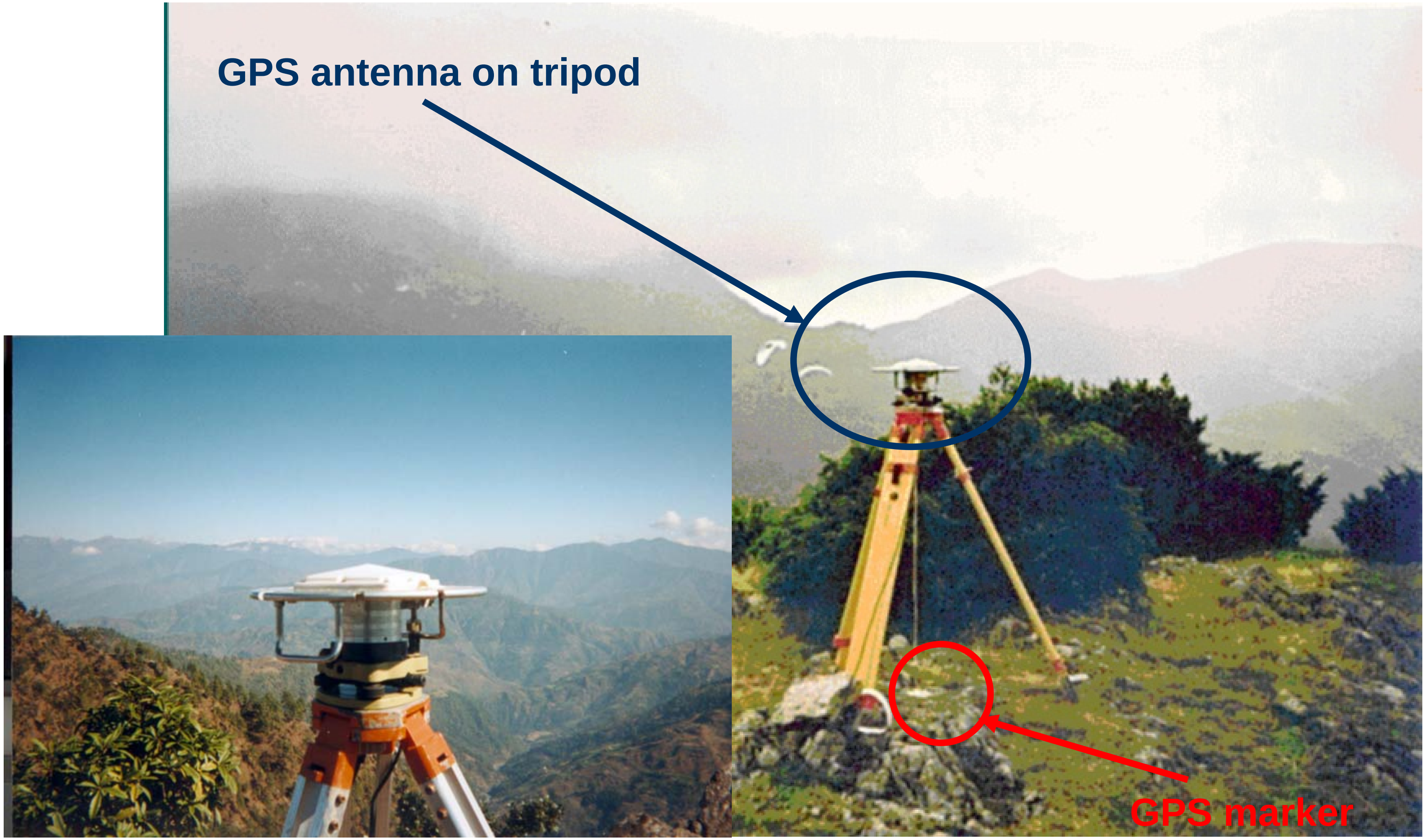
Phase Measurement:

Accurate to 20 mm on L1 or L2 (1.5 GHz)

But difficult because the initial offset is unknown.

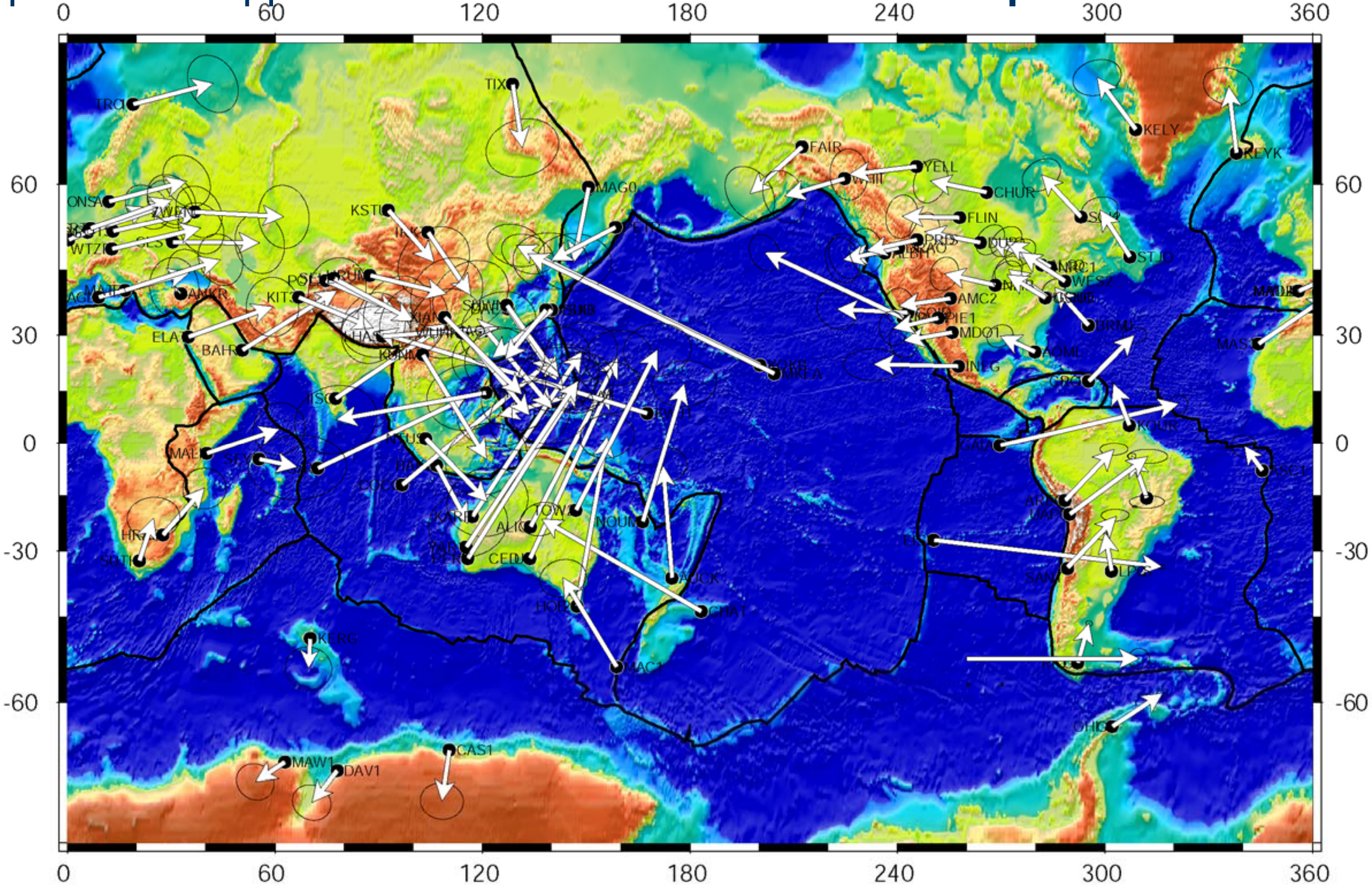
=> Post processing of a sequence of measurements on 1 satellite give final station position

GPS (Global Positioning System)

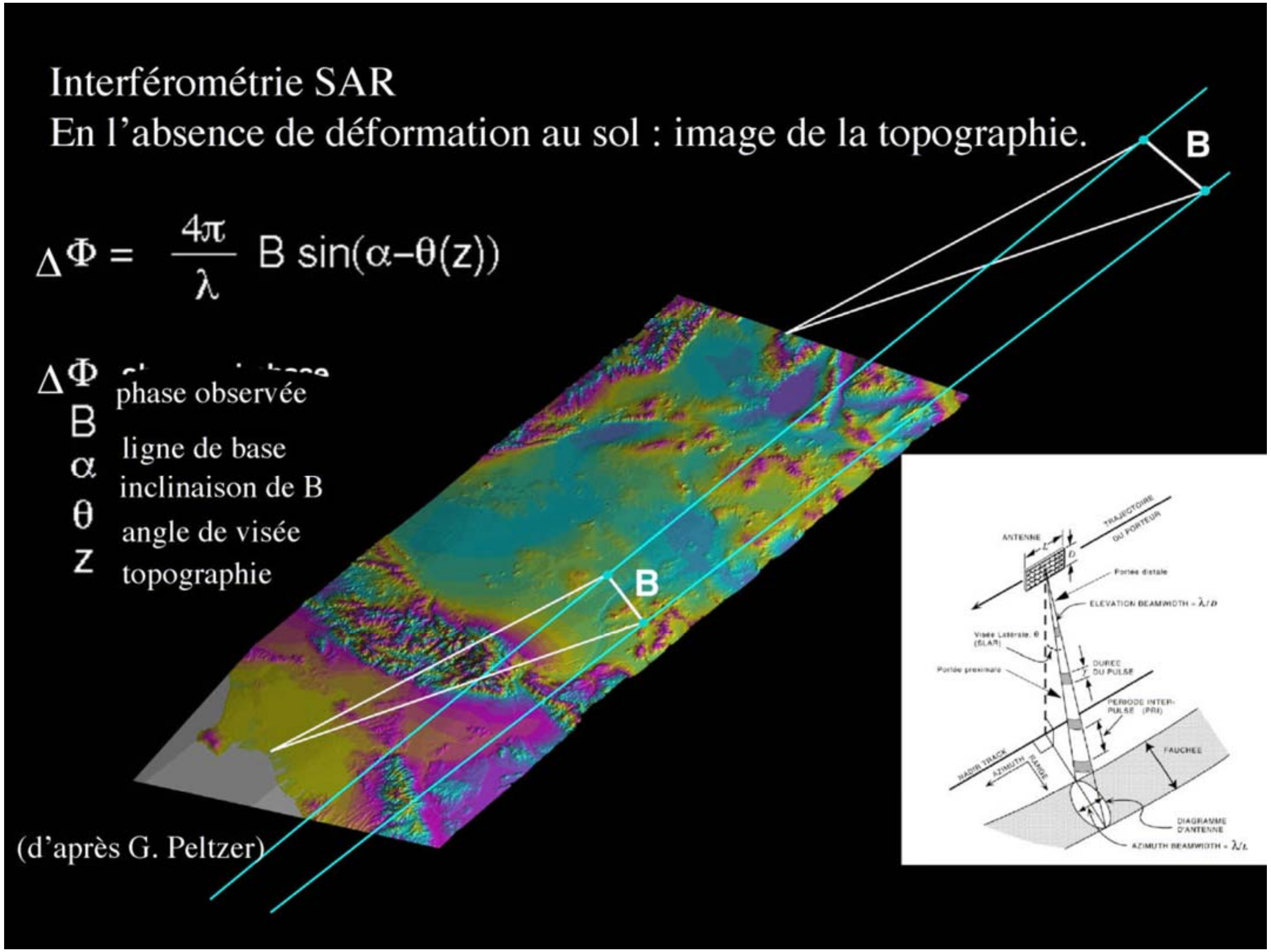


GPS (Global Positioning System)

A spectacular application of GPS : the measurement of **plate tectonics**



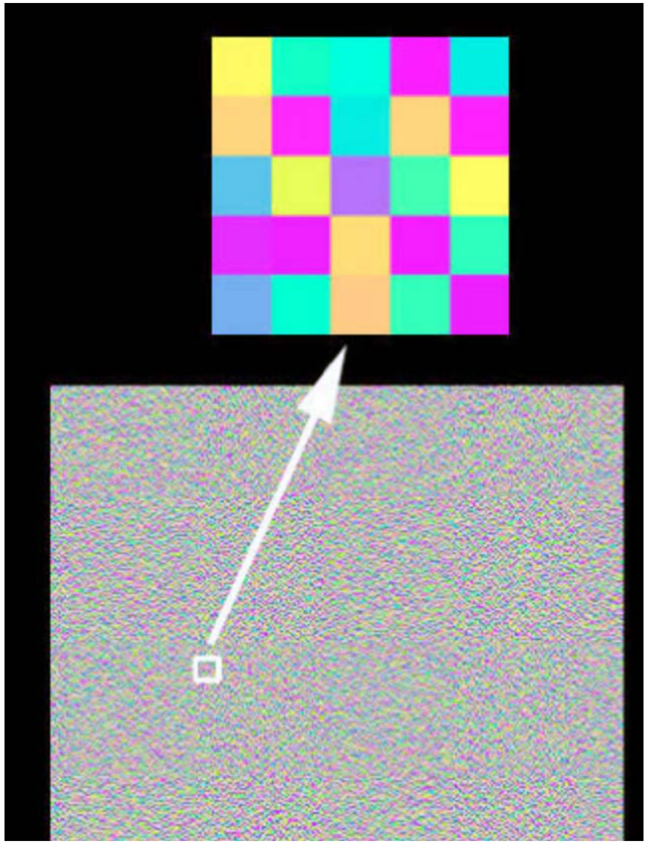
INSAR (Synthetic aperture Radar interferometry)



INSAR Phase coherence

Locally, the phase in a SAR image is not coherent

But the phase difference between 2 images on the same area is coherent and show the deformation



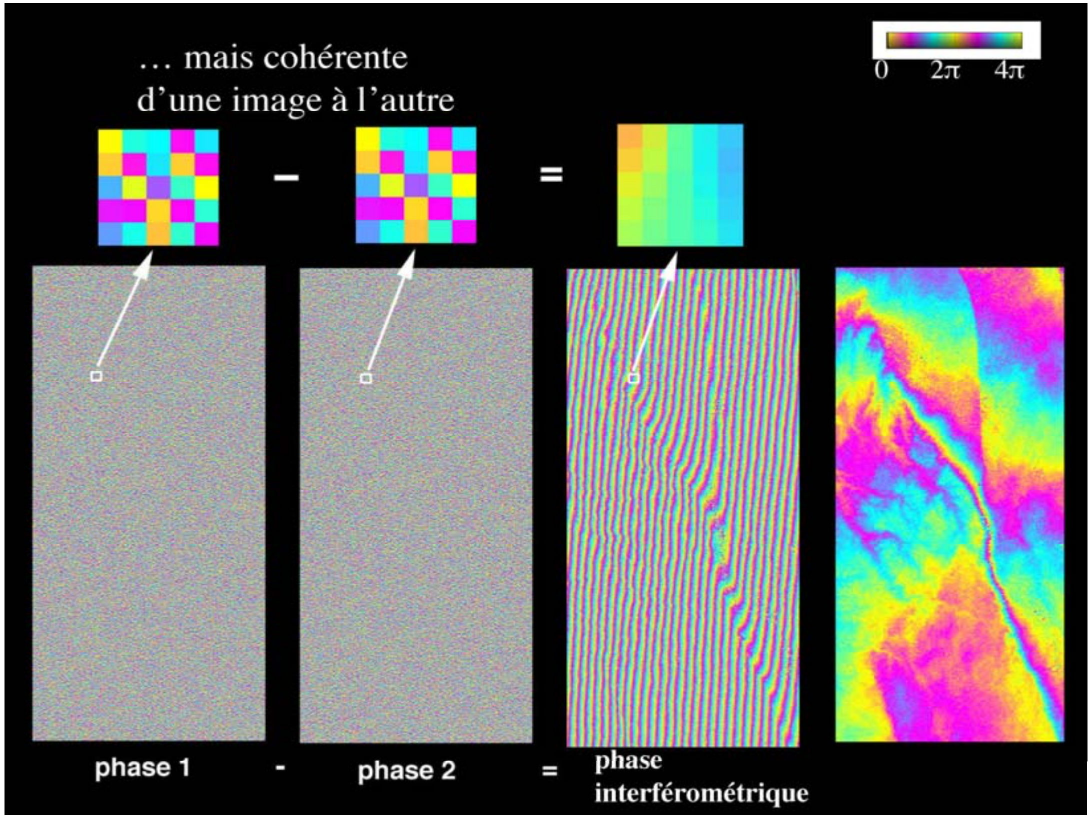
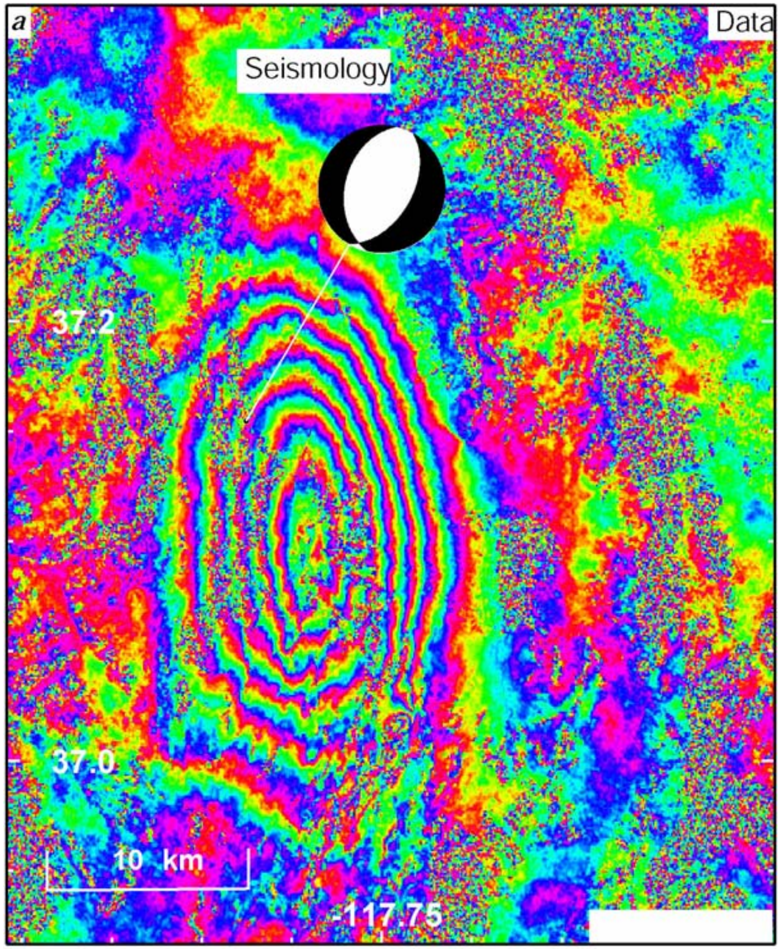
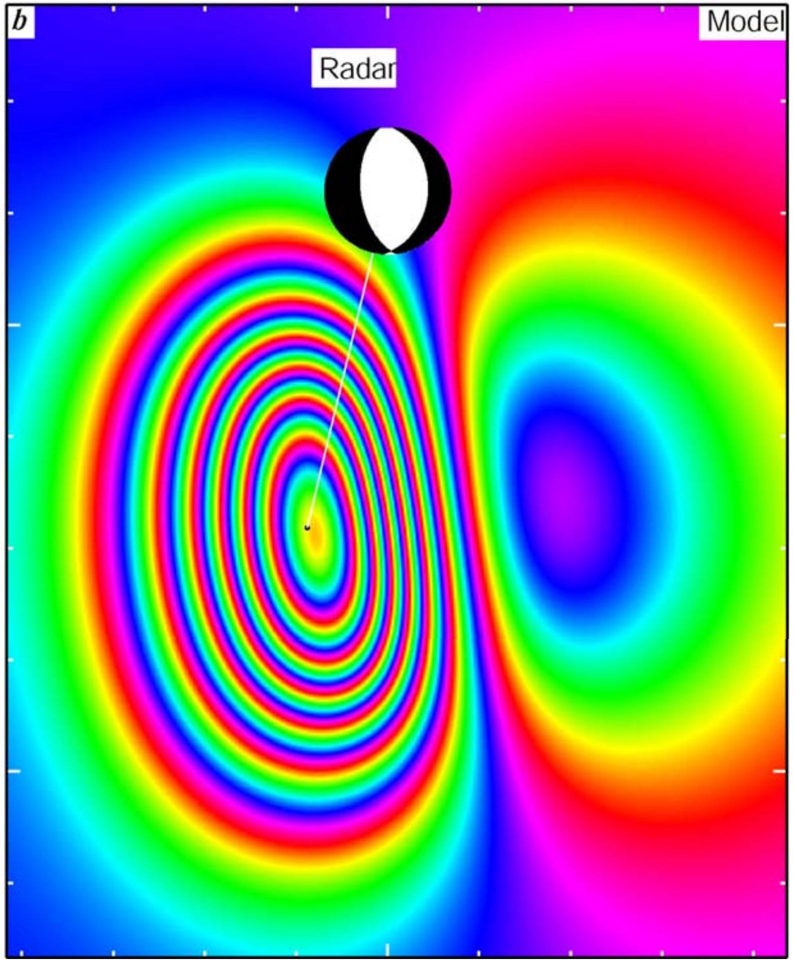


Image of an Earthquake : Co-seismic interferogram



Real data



model

Co-seismic interferogram example

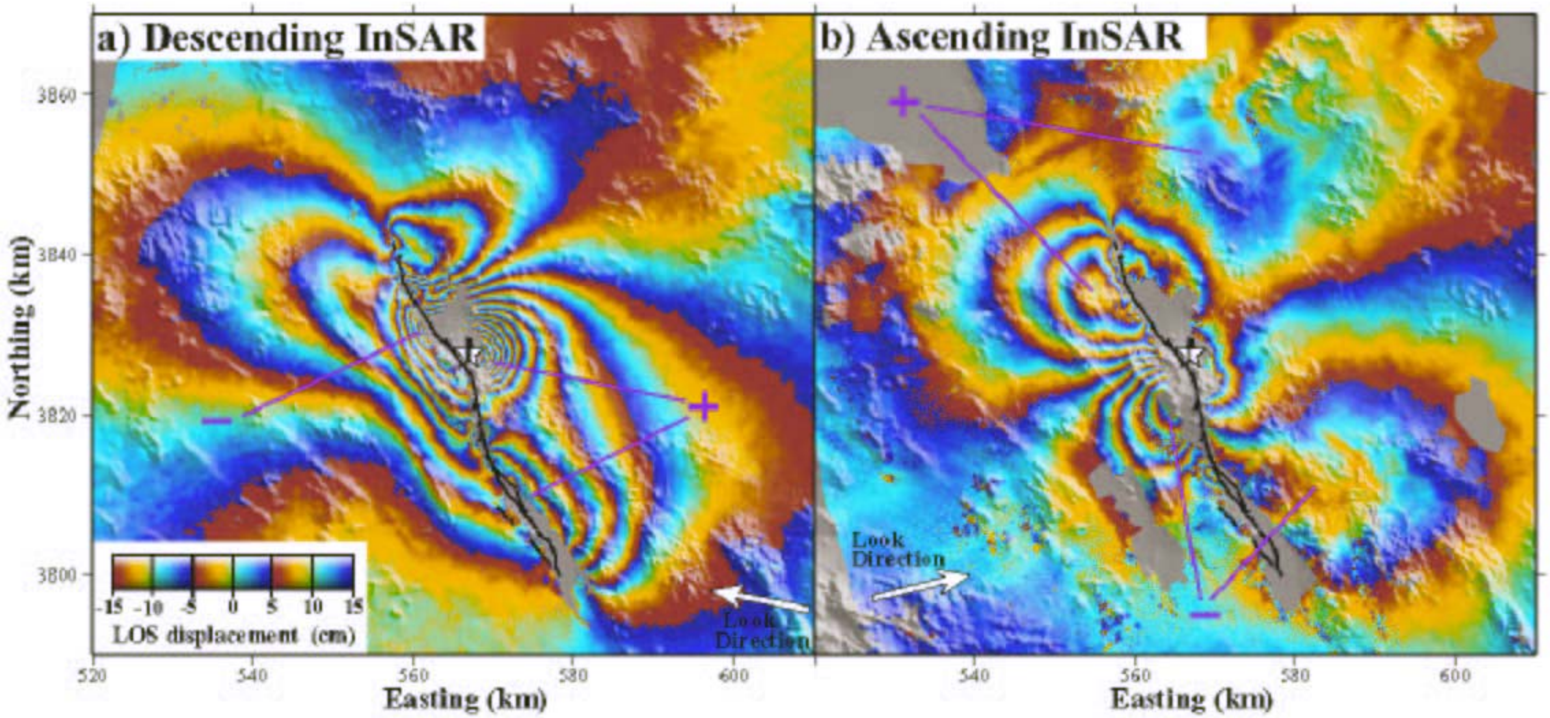


Figure 2: (a) Descending and (b) ascending interferograms showing the deformation of the Hector Mine earthquake. Each color cycle represents 10 cm of line-of-sight (LOS) displacement toward (yellow-red-blue) or away from (yellow-blue-red) the satellite. Arrows show the horizontal component of the look direction from the radar satellites. Purple + and – signs point to areas of positive and negative LOS displacement. The mapped fault trace is shown as thick line and the epicenter is denoted with a star. Coordinates are universal transverse Mercator (UTM) coordinates (zone 11S) in kilometers.